

A VISCOSITY PRIMER: VISCOSITY DEFINITIONS

Viscosity

Definition: A measure of the resistance of flow due to internal friction when one layer of fluid is caused to move in relationship to another layer. The Poise represents absolute viscosity, the tangential force per unit area of either of two horizontal planes at unit distance apart, the space between being filled with the substance. A liquid with an absolute viscosity of one Poise requires a force of one dyne to maintain a velocity differential of one centimeter per second over a surface one centimeter square. When the ratio of shearing stress to the rate of shear is constant, as is the case with water and thin motor oils, the fluid is called a Newtonian fluid. In the case of non-Newtonian fluids, the ratio varies with the shearing stress, and viscosities of such fluids are called apparent viscosities. In the new SI system, it is proposed that values for the Poise be stated as Pascal seconds, the conversion factor being 1 Poise equal to 1×10^{-1} Pa·s. A common measurement unit is the milliPascal second (mPa·s). Conversion factors are as follows:

1 centipoise (cP) = 0.01 poise (P)

1 Pa·s = 10 P

1 cP = 0.001 Pa·s = 1 mPa·s

1 Pa·s = 1000 cP

Absolute Viscosity

Definition: The tangential force per unit area of two parallel planes at unit distance apart when the space between them is filled with a fluid and one plane moves with unit velocity in its own plane relative to the other. Also known as coefficient of viscosity.

Apparent Viscosity

Definition: The value obtained by applying the instrumental equations used in obtaining the viscosity of a Newtonian fluid to viscometer measurements of a non-Newtonian fluid.

See also VISCOSITY.

Dilute Solution Viscosity

Definition: The viscosity of a dilute solution of a polymer, measured under prescribed conditions, is an indication of the molecular weight of the polymer and can be used to calculate the degree of polymerization. See also VISCOSITY, INHERENT; VISCOSITY, INTRINSIC; VISCOSITY, REDUCED; VISCOSITY, RELATIVE; and K-VALUE

K-Value

Definition: The K-value was introduced by Fikentscher [Cellulose Chem. 13.60 (1932)] for correlating relative viscosity with the average degree of polymerization. K-values are used in the cellulose and PVC industries and more commonly in Europe. The equation due to Fikentscher is:

$$\frac{\log_{10}(\eta_{rel})}{c} := \frac{75 \cdot k^2}{1 + 1.5 \cdot k \cdot c} + k$$

c is concentration in g/dL (g/100mL) and k is the Fikentscher parameter. The commonly reported K-values are represented in upper case and are simply related to the Fikentscher k by a factor of 1000: $K = 1000 \times k$.

The Fikentscher equation can be solved for K:

$$K := \frac{a - 1 + \sqrt{1 + a^2 + 2 \cdot a \cdot \left(1 + \frac{100}{c}\right)}}{0.15 + 0.003 \cdot c}$$

$$\text{where } a = 1.5 \times \log_{10}(\eta_{rel})$$

A point of confusion can be avoided by noting that the Fikentscher equation uses a base10 logarithm as opposed to the natural logarithm present in the definition of the inherent viscosity.

Kinematic Viscosity

Definition: The absolute viscosity of a fluid divided by the density of the fluid. Also known as the coefficient of kinematic viscosity. Measured in stokes (St) or centistokes (cSt). One centistoke = 0.01 stokes. The metric unit is square metres per second (m^2/s). A common metric measurement unit in glass capillary viscometry is millimeters squared per second (mm^2/s). Conversion factors are as follows:

$$1 \text{ St} = 1 \times 10^{-4} m^2/s$$

$$1 m^2/s = 10,000 \text{ St}$$

$$1 \text{ cSt} = 1 \times 10^{-6} m^2/s = 1 \text{ mm}^2/s$$

$$1 m^2/s = 1,000,000 \text{ cSt}$$

Centistokes may be converted to centipoise (cP) by multiplying by the density of the fluid being measured, all measured at the same temperature

Intrinsic Viscosity ($[\eta]$)

Definition: The ratio of a solution's specific viscosity to the concentration of the solute, extrapolated to zero concentration. Intrinsic viscosity reflects the capability of a polymer in solution to enhance the viscosity of the solution. The viscosity behavior of macromolecular substances in solution is one of the most frequently used approaches for characterization. The intrinsic viscosity number is defined as the limiting value of the specific viscosity/concentration ratio at zero concentration. Intrinsic viscosity is determined by measuring the relative viscosity at several different concentrations and then extrapolating the specific viscosity to zero concentration. The variation of the viscosity number with concentration depends on the type of molecule as well as the solvent. In general, the intrinsic viscosity of linear macromolecular substances is related to the molecular weight or degree of polymerization. With linear macromolecules, viscosity number measurements can provide a method for the rapid determination of molecular weight when the relationship between viscosity and molecular weight has been established. Intrinsic viscosity is calculated by determining the reduced viscosity (η_{sp}/c) and extrapolating to infinite dilution.

Huggins equation

$$[\eta] = \lim_{c \rightarrow 0} \eta_{red}$$

Craemer equation

$$[\eta] = \lim_{c \rightarrow 0} \eta_{inh}$$

Where: c = concentration of polymer in grams per 100 milliliters of solution
Also known as LIMITING VISCOSITY NUMBER.

Inherent Viscosity (η_{inh})

Definition: The quotient of the natural logarithm of relative viscosity and the concentration.

Inherent viscosity (η_{inh}) is expressed in the following equation:

$$\eta_{inh} = \frac{\ln \eta_{rel}}{c}$$

Where:

c = concentration

η_{rel} = relative viscosity (unitless ratio)

Reduced Viscosity (η_{red})

Definition: The specific viscosity (η_{sp}) divided by the concentration, expressed in g/ml. Also known as VISCOSITY NUMBER.

Reduced viscosity (η_{red}) is expressed in the following equation:

$$\eta_{red} = \frac{\eta_{rel} - 1}{c}$$

Where:

c = concentration

η_{rel} = relative viscosity (unitless ratio)

Relative Viscosity (η_{rel})

Definition: The ratio of the viscosities of the polymer solution (of stated concentration) and of the pure solvent at the same temperature. Also known as SOLUTION SOLVENT VISCOSITY RATIO.

Relative viscosity (η_{rel}) is expressed in the following equation:

$$\eta_{rel} = \frac{\rho_1(C_1 t_1 - E_1/t_1^2)}{\rho_0(C_0 t_0 - E_0/t_0^2)}$$

Where:

ρ = density

C = tube calibration constant (cSt/s)

E = kinetic energy correction constant (cSt·s²)

t = flow time (seconds)

Specific Viscosity (η_{sp})

Definition: The relative viscosity of a polymer solution of known concentration minus 1; usually determined at low concentration of the polymer; for example, 0.5 gram per 100 milliliters of solution, or less.